DEGRADATION MODELLING ON THE INFLUENCE OF MOISTURE CONTENT UPON BURST CAPACITY OF COMPOSITE REPAIRED PIPELINE

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Saluran paip adalah cara yang paling digemari untuk mengangkut gas/cecair dalam kuantiti yang besar. Sepanjang perkhidmatan sistem saluran paip keluli, ia digunakan dalam persekitaran yang berbeza yang akan menyebabkan kemerosotan paip keluli. Kini, komposit polimer deperkuat gentian (*FRP*) semakin pesat digunakan untuk membaiki saluran paip keluli dan ia telah terbukti berkesan. Apabila sistem pembaikan komposit terdedah kepada persekitaran yang agresif, terdapat pelbagai faktor yang boleh menjejaskan kekuatan komposit termasuk kelembapan, suhu, keasidan, kebakaran dan ultraviolet. Oleh itu, kajian ini bertujuan untuk menentukan ketahanan komposit serat tikar cincang kaca-epoksi (*chopped strand mat glass fibre/epoxy*) dibawah kesan penyerapan kelembapan dengan menggunakan simulasi analisis unsur terhingga (*FEA*). Komposit direndam dalam air selama 28 hari berturutan pada suhu bilik. Kandungan lembapan komposit berada pada 1.078%, 2.758%, 3.693%, 4.100% dan 4.121% dalam masa 1, 7, 14, 21, dan 28 hari. Terdapat lima model unsur terhingga telah dihasilkan untuk mengkaji kesan kelembapan ke atas tekanan letus. Dapatan dari analisa unsur terhingga (*FE*) menunjukkan sedikit penurunan tekanan letus iaitu 31.663MPa (penurunan sebanyak 0.994%) pada 28 hari dengan kandungan lembapan sebanyak 4.121%. Kekuatan tegangan yang rendah daripada komposit membawa kepada kekurangan sumbangan ketahanan tekanan. Kesan kelembapan komposit kurang jelas ditunjukkan dengan menggunakan serat tikar cincang kaca-epoksi. Walaupun hasil kajian menunjukkan kelembapan tidak banyak memberi kesan terhadap tekanan letus, namun terdapat trend yang menunjukkan penurunan tekanan letus apabila kandungan kelembapan bertambah. Peningkatan kandungan kelembapan akan mengurangkan kekuatan tegangan komposit dan mengakibatkan penurunan tekanan letus. Satu ramalan jangkahayat perkhidmatan paip keluli dibaiki komposit telah dilakukan untuk meramal baki hayat perkhidmatan bagi tujuan menunjukkan bagaimana keputusan dalam kajian ini boleh digunakan oleh pengendali saluran paip. Tekanan letus dijangka berkurangan sebanyak 53.097% berbanding dengan model kawalan iaitu dari 31.981MPa kepada 15MPa selepas 178 hari.

ABSTRACT

Pipelines are most favored mode of transportation of gas/liquid in large quantities. Along the service life of steel pipeline system, it exerted in different condition of surrounding which cause deterioration of steel pipeline. There is a rapid growth in the application of Fibre-Reinforced Polymer (FRP) composites wrap where the method has been proven effective for repairing steel pipelines. When composite repair system exposed to aggressive environment, there are various factors which may affect the strength of composite include moisture, temperature, acidity, fire and ultraviolet. This study aims to determine the durability of chopped strand mat glass fibre/epoxy composite under the effect of moisture absorption using finite element analysis (FEA) simulation. The composite was immersed into water for 28 days at room temperature. The moisture contents of composite were 1.078%, 2.758%, 3.693%, 4.100%, and 4.121% on immersion time of 1, 7, 14, 21, and 28 days, respectively. Five finite element models were developed to study the moisture effect toward burst pressure. The FE result shows a slightly drop for burst pressure on 28-days which was 31.663MPa (0.994% drop) with moisture content of 4.121%. The low tensile strength of composite lead to less contribution toward stress sustainability. The moisture effect of composite was not obviously shown by using chopped strand mat glass fibre-epoxy. Although the result shows not much effect of moisture toward the burst pressure, but there was a trend shows the decreasing of burst pressure when moisture content increases. The increase of moisture content decreases the tensile strength of composite and resulted in decreasing of burst pressure. A prediction of long-term service life of composite repaired steel pipe was performed to forecast its remaining service life to demonstrate how the results in this study can be used by the pipeline operators. The burst pressure was predicted to reduce by 53.097% compared to control model which drop from 31.981MPa to 15MPa after 178 days.

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LIST OF SYMBOLS

E	Young's Modulus
G	Tensile modulus
v	Shear modulus

LIST OF ABBREVIATIONS

PG&E	Pacific Gas and Electric Company
FRP	Fibre-Reinforced Polymer
UV	Ultraviolet
UTS	Ultimate tensile strength
TTS	Time-temperature superposition
FEA	Finite Element Analysis
USA	The United States of America
BP	Burst pressure
FE	Finite Element

CHAPTER 1

INTRODUCTION

1.1 Overview

Pipelines function as blood vessels serving to transport life-necessities such as water or natural gas, oil and to take away life waste like sewage (Central Intelligence Agency, 2018). Pipeline are also considered to be the most favoured mode of transportation of gas/liquid in large quantities (Kishawy and Gabbar, 2010). According to a database published by the United State of America's Central Intelligence Agency, there are over one million kilometres of pipelines laid around the world to transport oil and natural gas (Central Intelligence Agency, 2018). Along the service life of steel pipeline system, it exerted in different condition of surrounding such as aggressive environments with high pressures and high temperatures which cause deterioration of steel pipeline. The degradation of pipeline may lead to leaking, fire and explosion. In regard to urban natural gas pipeline accidents, corrosion is one of the major causes (Muhlbauer, 2004). Pipeline failure due to corrosion attack can cause hazards involving multiple fatalities, serious financial loss, bad economic implications, and significant environmental damage (Yahaya et al., 2009).

As reported by the National Transportation Safety Board (2011), an explosion of a natural gas pipeline in San Bruno, California, owned by Pacific Gas and Electric Company (PG&E), killed eight people, injured 58 others, destroyed 38 houses, and damaged 70 more in a residential neighbourhood. According to The Star Online, there is a fire broke out on Tukau B drilling platform with 60m-deep underwater inside the vicinity of the Tukau Oilfield, located 31km from the Miri shoreline that belonging to Petronas in deep waters in the South China Sea. There were 16 peoples on board doing maintenance work on the platform during the fire had been successfully evacuated and

the fire was doused in an hour (Stephen, 2012). In preventing the risk and hazardous to occur, maintenance, checking by using pigging and safety are very significant to carry out. There is more than 35% of Malaysia local onshore pipeline are more than 30 years old (Petronas Gas Berhad, 2014). Therefore, in order to ensure the serviceability of pipeline system to continue safely, rehabilitation of structurally compromised pipelines is needed.

There is a wide range of rehabilitation techniques and repair methods available for onshore and offshore pipelines. To repair corroded steel pipeline, several method can be used such as, applying grout, installing full-encirclement steel sleeve or steel clamp, or remove the entire corroded pipe to replace a new pipe if condition is critical (Noor et al., 2016). Apart from that, there is a rapid growth in the development and application of FRP composites wrap recently where the method has been proven effective for repairing steel structures such as risers and pipelines (Duell et al., 2008; Leong et al., 2011; Alexander, 2014; Chan et al., 2015).

1.2 Problem Statement

Fibre-Reinforced Polymer (FRP) composite wrap is increasingly used as rehabilitation technique of pipeline system. In order to optimise the design of composite repair system, the load bearing capacity of FRP composite wrap is important. However, the performances of FRP composite wrap in various environment conditions are not fully understood. Their durability and integrity in various service environments depends of the response of its constituents i.e., fibre, polymer matrix, and the existing interface between the fibre and polymer matrix, in that particular environment (Sethi and Ray, 2015). When composite repair system exposed to environment, there are various factors which may affect the strength of FRP composite wrap over time include UV, temperature, acidity, alkalinity, humidity, fire and moisture. According to Keller et al. (2013), carbon fibre/epoxy matrix composites that exposed to water for over 18 months are conservative for 50 years design life with maximum loading of 16% and 65% ultimate tensile strength (UTS) for time-temperature superposition (TTS) high-crimp composite and tensile creep test, respectively.

From the past literature, there is limited information regarding the load bearing capacity of the FRP composite warp that can help in predict how long it can sustain steel pipe until failure. The lack of durability data of FRP composite wrap not only lead to use of high factors of safety in design such as 4-6 in marine industry and 8-12 in the area of tanks and pipe (Helbling et al., 2006), it also increase the cost of overall repair system. The environmental condition that the pipeline structure located is significant to the degradation of FRP composite wrap. However, the lifetime durability validated data and knowledge are limited that make the research difficult. In this study, collection, assessment and appropriate documentation of available data of degradation FRP composite wrap were reviewed from previous research that used in civil structure. The parameters investigated in this study are glass fibre-reinforced polymer in epoxy matrix composite and the effect of moisture environment condition towards the strength degradation of the FRP composite. All the degradation data of FRP composite strength collected from previous research were utilised in Finite element analysis to predict the burst pressure and service life of steel pipe that are repaired by FRP composite.

1.3 Objective of study

This study aims to investigate the durability of FRP composite warp under the effect of moisture content over time upon burst capacity of composite repaired pipeline by finite element analysis (FEA). The objectives of this study are:

1. To investigate of the strength degradation of FRP composite wrap under the effect of moisture variation.
2. To determine the burst pressure of composite repaired pipeline subjected to degradation of composite wrap under different moisture condition.
3. To determine the remaining service life of pipeline repaired by FRP composite wrap.

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